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TELEMETRY FORMAT SYNCHRONIZER AND DECOMMUTATOR IN THE UNIFIED TELEMETRY SYSTEM GROUND STATION

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16. Abstract

The principles of the design of a telemetry format synchronizer and decommutator in the unified telemetry system (UTS) ground station are discussed.

Probability values for missing the frame interval are analyzed, as well as the detection of false frame intervals for various signal to noise ratios; the sequence of operation of the format synchronizer is also examined.

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TELEMETRY FORMAT SYNCHRONIZER AND DECOMMUTATOR
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V. V. Lavrusevich

Introduction /3*

One of the basic and highly advanced methods of transmitting scientific space information is the digital method, which permits us to raise the accuracy of measurements and to reduce significantly the time required for the processing of information recorded on magnetic tape with the aid of the electronic digital computer. However, for many reasons (the necessity of obtaining separate telemetering constants (TC) at the time of reception, monitoring of the operation of TC units by means of the visualization of the frame interval (FI) etc.), it is necessary to accomplish operational decommutation of information directly at the receiving station at the time of the communications period with the artificial Earth satellite (AES). This problem is solved with the aid of the telemetry constant format synchronizer.

Much work, both of a theoretical and of an applied nature, has been devoted to the question of frame synchronization. In [6] methods of TC frame synchronization have been investigated utilizing distributed and combined frame intervals. J. Massey [7] investigated an optimal method of detecting a concentrated frame interval in a binary pulse code modulation (PCM) stream with additive white Gaussian noise present in the channel. In [3] the author analyzes two methods of frame synchronization, one of which takes into consideration average synchronization time, while the second examines the synchronization process in the form of a model with a specific number of states. The works [1, 2, 4, 5] are devoted to the problem of designing frame synchronization devices. In this work we express the principles of designing a format synchronizer and devices for decommutation of binary TC information as applied to the TC structure of the unified telemetry system of UTS.

*Numbers in the margin indicate pagination in the foreign text.

I. Design Analysis of the Format Synchronizer /4

1. Error Probability Values

The format synchronizer (FS) of TC information separates from the binary PCM stream, which is obtained from the decision-making equipment, a specific segment (vector), consisting of L symbols and called the frame interval (FI). In this case we assume that the symbol synchronization has already been obtained. The digital PCM stream at the input of the FS has the form

$$\sum_{k=-\infty}^{+\infty} a_k \delta\left[t-k\left(1\pm\frac{\Delta T}{T}\right)T\right], \tag{1}$$

where a_k is the k-th symbol of the PCM stream; the symbols 1 and 0 are distributed within the stream with equal probability P(0) = P(1) = 1/2; $\delta(t)$ is a function determined by the expression

$$\delta(t) = \begin{cases} 1, & t \in (0,T) \\ 0, & t \notin (0,T) \end{cases} \tag{2}$$

T is symbol duration; $\Delta T/T$ is the relative difference in synchronization between airborne and ground symbol frequency generators.

The FS is characterized by two types of errors, which include the false alarm (incorrect detection of the FI) and target omission (missing of the FI). We shall evaluate the error probability values of the errors specified. Due to the action of additive white Gaussian noise and intersymbol interference, the individual FI symbols will be distorted; therefore the FS as a rule, will be constructed on the principle of correlation detection, rather than as a detector with a given binary vector.

The probability of correct FI detection is P, when FS permits up to "α" errors, calculated from the formula

$$P = \sum_{i=0}^{\alpha} C_l^i p^i q^{l-i} \tag{3}$$

where α is the number of errors denoted by the FS; C_l^i is the binomial coefficient; /5
P is the probability of incorrect symbol recognition; q = t - P; L is the number of symbols in the FI. The probability of missing the FI, i.e., Q has the form

$$Q = 1 - P = \sum_{i=\alpha+1}^{l} C_l^i p^i q^{l-i} \tag{4}$$

In determining the probability of incorrect FI detection, we must examine two cases: false detection of the FI in the informational stream of random bits (F), and the false detection of the FI in the neighborhood of the distribution of a specific binary vector of L symbols, which form the FI(F_S). These are determined in agreement with the expression

$$F = \frac{1}{2^L} \sum_{i=0}^{\alpha} C_L^i, \tag{5}$$

where $\frac{F}{2^L}$ is the probability of a specific combination (FI) of L symbol; C_L^i is the possible number of combinations up to "α" errors in the l-bit word.

$$F_{+S} = \frac{1}{2^S} \sum_{i=M_S-\alpha}^{M_S} C_{M_S}^i p^i q^{M_S-i} \sum_{j=0}^{\alpha} C_{L-M_S-S}^j p^j q^{L-M_S-S-j}, \tag{6}$$

where S is the number of symbols corresponding to displacement of the frame synchronization signal in conjunction with erroneous detection (S may vary from 1 to L - 1); M_S is the number of symbols which correspond to noncoincidence of the binary vector L during FI displacement by S symbols.

Figure 1 shows a conventional image of TC frame, containing N symbols with the FI consisting of L symbols. Since random informational symbols are situated on both sides of the TC, $F_{+S} = F_{-S}$. F_{+S} means that false frame synchronization is encountered with a leading effect by S symbols with respect to the true synchronization, while F_{-S} characterizes a lagging by S symbols. /6

The FI in the UTS consists of 30 symbols and has the appearance: 101001000010101110110001111100. It can be shown that where F = 1; 2; 3, the value M_S = 15; 13; 15, respectively. Table 1 shows probability values P for FI omission and incorrect FI detection, calculated from the formulas (4)-(5) by means of [8], for three fixed values of incorrect symbol identification and three assumed error values (α) in the FI.

2. Order of Operation of the FS

Detection of the FI involves solving the problem of finding a signal with characteristics known in advance that with an unknown distribution in the binary PCM stream. Ordinarily the FS passes through 3 operational modes; these include search, which involves the time devoted to analysis of arriving information; checking, which involves the time in which the FS accomplishes confirmation of the initially detected FI and makes a final decision; and the tracking mode, when the FI is located and even the presence of random errors of the type involving FI omission, or false FI detection do not lead to break up of frame synchronization.

TABLE 1. /7

	$\alpha = 1$			$\alpha = 2$			$\alpha = 3$		
β	10^{-3}	10^{-4}	10^{-5}	10^{-3}	10^{-4}	10^{-5}	10^{-3}	10^{-4}	10^{-6}
ζ	790.10^{-6}	450.10^{-6}	391.10^{-6}	368.10^{-6}	446.10^{-6}	391.10^{-6}	364.10^{-6}	446.10^{-6}	391.10^{-6}
F	$2{,}98.10^{-8}$			$4{,}3.10^{-7}$			$4{,}22.10^{-6}$		

Commas indicate decimal points.

A suitable device for the detection of the FI is the digital correlator which includes an L-bit shift register, L "exclusive AND," circuits and an adder. In contrast to coincidence circuits, which at full correlation provide maximum signal at the adder output, the "exclusive AND" circuits form noncoincidence signals which provide for the convenient engineering solution to the threshold circuit problem.

The output signal of a given digital correlator is an inverse correlation function and has discrete values determined by the formula /8

$$U_{out} = \sum_{i=1}^{L} g_i \oplus R_i , \tag{7}$$

where $g_1, g_2, \ldots g_L$ are binary components of varying vector L, passing through the shift register; $R_1, R_2, \ldots R_L$ are binary components of the fixed vector R corresponding to the FI. Figure 2 shows a block diagram of the digital correlator, where 1 is the shift register in L places, 2 is the code exclusive AND circuit, and 3 is the current generator. The threshold unit with a varying threshold level, together with the digital correlator, makes it possible to formulate the FI identification signal. There is described in [2] an FS with an automatically variable threshold, depending on the characteristics of the received PCM stream; this FS always has a very high probability of correct FI detection. The natural consequence of this is the exceptional complexity of the equipment, which in reality is a small specialized computer. Nevertheless Peavy [4] investigated frame synchronization problems by means of the fixed threshold method, and revealed it had a range of bit error up to 10% and with little loss in information receipt time, and that it is possible to realize a very small probability of incorrect FI detection.

The probability P_α that L is a bit word of the FI containing α errors has the form

$$P_\alpha = C_L^\alpha p^\alpha q^{L-\alpha} \tag{8}$$

the value P_α for L = 30; the values P_α for L = 30, three values of P, equal to 10^{-3}, 10^{-4} and 10^{-5}, as well as three values of errors α, equal to 1, 2, and 3, calculated by means of [8] are shown in Table 2. /9

TABLE 2.

P	P_α		
	α = 1	α = 2	α = 3
10^{-3}	$2{,}913 \cdot 10^{-2}$	$4{,}2283 \cdot 10^{-4}$	$3{,}9504 \cdot 10^{-6}$
10^{-4}	$2{,}990 \cdot 10^{-3}$	$4{,}3360 \cdot 10^{-6}$	$4{,}0474 \cdot 10^{-9}$
10^{-5}	$2{,}998 \cdot 10^{-4}$	$4{,}3472 \cdot 10^{-8}$	$4{,}0574 \cdot 10^{-12}$

Commas indicate decimal points.

The FI quantity for a communications period was an AES was determined from formula (9):

$$K = 60\,\frac{t \cdot F}{A \cdot B}, \tag{9}$$

where t is the duration of the communications period with the AES in [min]; S is the bit rate $[\frac{\text{bit}}{\text{sec}}]$, A is the number of bits in the TC word; B is the number of words in the TC frame. Where $t \simeq 10$ min, $F \simeq 10{,}923\ \frac{\text{bit}}{\text{sec}}$, A = 10 bits, B = 64; $K \simeq 10^4$. Thus, where $p = 10^{-3}$ for one communications period there will be on the average one error symbol where $\simeq 290$ FI occurrences are involved, and one error where $\simeq 4$ occurrences are involved. Three errors in the FI with a given value B will be encountered approximately one time during 4 hours and 16 minutes of uninterrupted work. In this case it is advantageous to use a switchable varying threshold, considering up to 3 errors in the FI.

It is apparent from Table 1 that the probability values for FI omission and the appearance of a false FI may reach up to $790 \cdot 10^{-6}$ and $4.22 \cdot 10^{-6}$, respectively. For this reason protective devices must be incorporated in the FS. Figure 3 shows the block diagram for the formation of the frame synchronization signal γ, where 1 is a 640 symbol counter, which corresponds to the length of the TC frame of the UTS; 2 is a logic circuit which shapes the output signals f and γ /10 in agreement with the expression:

$$\left.\begin{aligned} f &= \varphi\cdot\bar{\beta} + \bar{\varphi}\cdot\beta \\ \gamma &= \varphi\cdot\beta \end{aligned}\right\} \qquad (10)$$

where γ is the output signal of the digital correlator; β is the output signal of the 640 symbol counter; f is a false signal which appears as a result of a false FI or as a result of FI omission; 3 is the averaging unit which prevents responses to errors in FI detection. In the case of systematic error during FI detection, the signal is formed at the output of unit 3 which causes a control trigger and the FS passes to the SEARCH mode.

Figure 4 shows a block diagram for the TC word decommutator. The initial signals for normal operation of this circuit are made up of a delayed frame synchronization signal γ_{del} and bit rate signals (clock pulses — CP). The signal γ_{del} is utilized for the initial adjustment. Groups of dividers by 10 and 6, together with decoders for tens (1) and units (2), as well as a commutator (3) for the TC number permit the selection of any TC number in the UTS format. Due to the possibility of FI omission with the appearance of a false FI, the decommutator unit has an "AND" circuit (4), which permits for the two dividers by 10 and 6 when the signal γ_{del} is missing.

A parallel PCM stream, taken from the first 10 places of the digital correlation shift register is applied to a key circuit which is also furnished with signals of the selected TC word. Thus the TC word is recorded in the buffer memory unit consisting of 10 flipflops and is reflected at 10 signal lamps through a coupling circuit (5).

In order to measure the individual characteristics of the FS, it is possible to use a PCM stream of the "pseudorandom frame" type [9], which consists of the /11 FI of the TC format of the UTS and a pseudorandom sequence of a given period (610 bits). In this connection we employ a noise generator, the output of which may be regulated in order to change the signal to noise ratio, as well as a PCM signal simulator. Under various noise level conditions a count of the quantity of frame synchronization identification signals is made and a comparison is accomplished with the true number of frames. The PCM signal simulator has a special output signal which is generated by a combined frequency detector and which appears once during the frame.

Figures

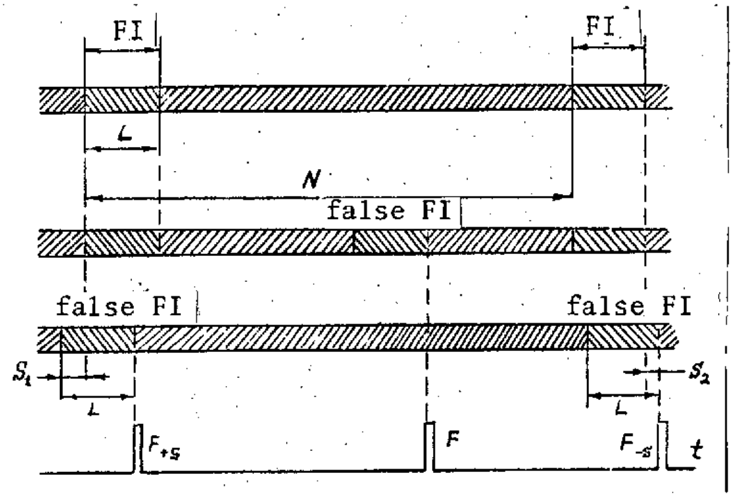

Figure 1. Conventional Representation of the TC Frame. /14

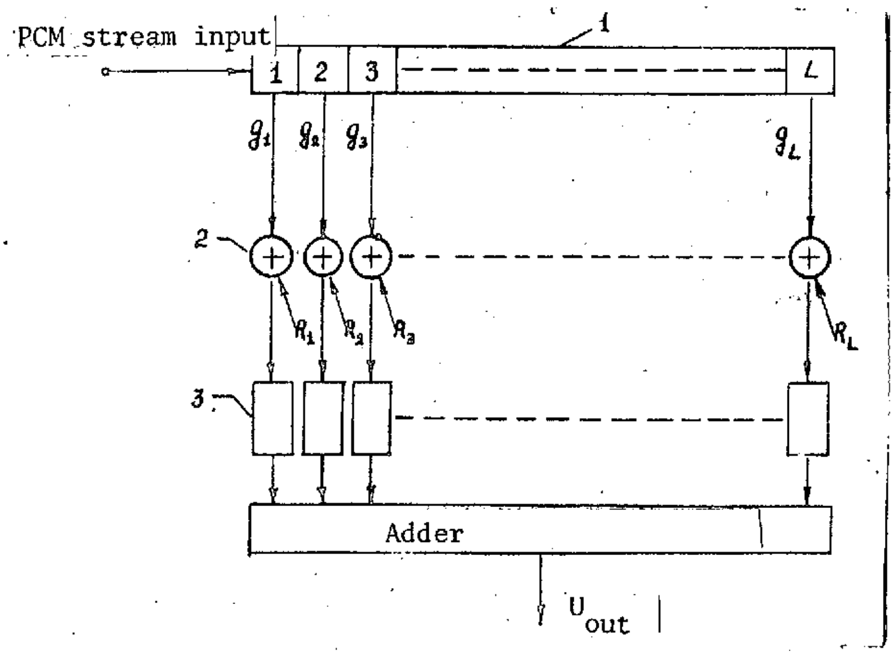

Figure 2. Block Diagram of the Digital Correlator.

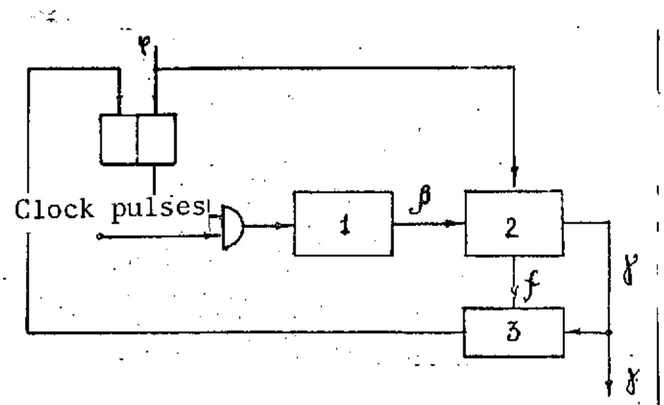

Figure 3. Block Diagram of the Frame Synchronization Signal Formation. /15

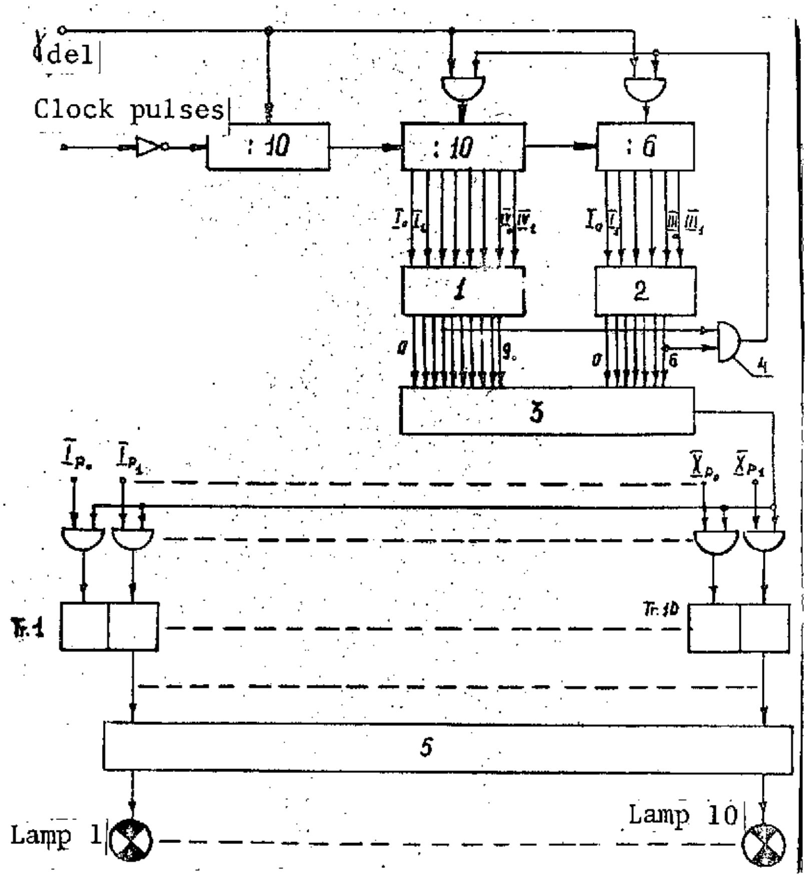

Figure 4. Block Diagram of the TC Word Decommutator.

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